Guglielmo Marconi and the History of Radio – Part I

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Personal Technical Assistant to G. Marconi, 1926 – 1936

G. A. Isted was born in 1903 and joined the Marconi Company at Chelmsford in 1923. In 1926 he was transferred to G. Marconi's private laboratory in London. In 1929 he was sent to Italy as Marconi's personal technical assistant and participated in Marconi's microwave experiments. When hostilities broke out between Italy and Abyssinia in 1935, he was recalled to England where he joined the staff of T. L. Eckersley who was studying radio wave propagation, mostly at Gt. Baddow. During World War II, he was in charge of the RAF section of the Inter-Services Ionospheric Bureau based at Great Baddow. Subsequent to Eckersley's retirement, he became Chief of the Marconi Radio-wave Propagation Group. He was largely responsible for the success of the nationwide coverage of the Independent Television Authority Band III television service. He retired in 1969 after 46 years with the Marconi Company.

A study of the developments leading towards a practical system of wireless telegraph communication clearly shows that there were five independent but complementary streams which scientists and engineers followed. These streams converged and eventually coalesced between the years 1890 and 1896.

The first and most important stream was followed by the scientists who indicated the presence and nature of the medium in which wireless waves could be propagated. The second stream was followed by the scientists and engineers who invented the means to generate electromagnetic waves. The third stream, also followed by scientists and engineers, yielded the means to detect electromagnetic waves after they had been transmitted. It is worthy of note that, at the time they were invented, these last two inventions were completely divorced from wireless telegraphy and from each other. The fourth stream was reserved for the engineers who already had their eyes on the practical application of communication by electricity without interconnecting wires and who carried out 'feeler' experiments, but who were hampered by the lack of experience and facilities. The final stream was followed by a series of unrelated events each having a close association with the new art.

The coalescence of these five streams into a viable system of communication was destined to revolutionize the lives of mankind.

Early Experiments

From the middle of the 19th century onwards the minds of telegraphic engineers were occupied with the idea that communication of the future would be by electrical installations that were not connected by wires, and many different experiments were carried out towards that end. Heinrich Hertz had not at this point produced his brilliant work showing how to generate and detect 'Maxwellian radiations'.

Most of the early wireless experiments were carried out by means of the induction system involving long wire circuits or conduction through the earth, but not by Hertzian waves. From the historical point of view, the Hertzian method of communication was somewhat obscured by these early experiments.

The first recorded attempt to communicate without interconnecting wires was made by Loomis in the United States. In 1858, he arranged for two separate vertical wires, 600 feet long, to be held aloft by kites on two mountain peaks 18 miles apart. Each wire was connected through a galvanometer to a coil of wire buried in wet ground. It was observed that, when one wire was connected or disconnected, the galvanometer needle in the other wire was deflected. It is claimed that Loomis did transmit intelligible messages over a distance of 14 miles in 1866. He patented his system of 'wireless' communication in 1872 but failed to get support to develop it further. The experiments are described in Loomis' notebook dated 1864, now lodged with the United States Library of Congress.

William Preece, Chief Engineer of the British Post Office, carried out tests of communication without connecting wires when, in 1882, the submarine cable between the Isle of Wight and the mainland broke down. Preece immersed two copper plates in the water on the mainland side of the Solent, separated by many miles, and connected them by an insulated wire. Correspondingly, he placed two more copper plates in the water along the Island side of the Solent, connecting them also by a wire. He then interrupted the mainland connecting wire at Southampton and the Island wire at Newport. He claimed that, when he inserted an instrument to make and break the current very rapidly with a buzzing sound and by using a Morse key and 30 Leclanché cells at Southampton, it was possible to read messages with a telephone at Newport, and vice versa.

In the following years, Preece carried out similar experiments at many places in the British Isles,

including the first series of tests between Lavernock and the island of Flat Holme in the Bristol Channel, a distance of 3.3 miles.

Probably the earliest successful attempt at communication by means of a system in which a single earth connection was used at each station was that carried out by Professor Dolbear who, in 1882, applied for an American patent for his system. In his final arrangement he connected one terminal of the induction coil transmitter to an earth plate; the other terminal he connected to a short vertical wire at the end of which was a large capacity plate. The receiver was an ordinary telephone, one side of which was connected to an earth plate, the other side to a short vertical wire with a large capacity plate at its end. Communication distances of up to half a mile were attained. In the apparatus described no mention is made of a spark-gap associated with the transmitter, nor of any detecting device apart from a telephone. It seems certain that electromagnetic radiation of the type that was soon to be demonstrated by Hertz was not involved, but the induction/earth current method so popular with experimenters then, combined with electrostatic excitation

It was in 1887 that the work of Hertz was to provide the breakthrough which paved the way for electromagnetic wireless communication. When he decided to investigate the problem of demonstrating experimentally that the properties of the electromagnetic field were as Maxwell described, he had the advantage of having the latest resources and knowledge at his disposal. He was well aware of the oscillatory nature of the disruptive discharge from a Leyden Jar and, with a Ruhmkorff induction coil providing the energy, he completed his transmitter by placing a 'Hertzian radiator' – consisting of two linear conductors – across the terminals of the spark-gap.

The receiver consisted very simply of a single loop of stiff wire broken by a small adjustable spark-gap. This loop was adjusted, or tuned, for maximum sparking across the small gap when the transmitter was functioning. The received energy was so feeble, however, that it had to be observed in a darkened environment.

By his experiments, Hertz was able to confirm the theories of Maxwell, for he was able to generate, detect and measure electromagnetic waves and their associated phenomena for the first time. He found a close relationship between these invisible waves and light, for he was able to further demonstrate that electromagnetic waves could be reflected, refracted and polarized just as light waves were.

Hertz's results caused a revolution in scientific thinking about electricity. Professor Oliver Heaviside is said to have exclaimed when learning of Hertz's results:

'Three years ago electromagnetic waves were nowhere; shortly afterwards they were everywhere.'

There is little doubt that man-made 'wireless' transmission was born in Hertz's laboratory. It seems strange that it did not then occur to Hertz to put his ideas and studies to practical use. It was for others to reap the benefit of such a promising start; but, nevertheless, it was to be several years before that happened.

Hertz died in 1894 at the early age of 37 and, five months later, Sir Oliver Lodge delivered a commemorative lecture on 'The Work of Hertz' at the Royal Institution, London. This lecture was remarkable in many ways. For the first time, it gave many people the opportunity to witness striking experiments performed with Hertzian or Maxwellian waves. These included experiments on their reflection, refraction and polarization, and their ability to pass through stone walls from room to room. Yet, although replete with interest, the lecture contained not even a hint of a possible application of electromagnetic waves to communication by telegraphy. The lecture was, in fact, a scientific demonstration of the undulatory character of the electromagnetic radiation from an oscillator and of the electromagnetic nature of ordinary light.

In a repeat lecture later in the same year to the British Association at Oxford, Lodge again demonstrated the fascinating properties of Hertzian waves. For one experiment, he placed in the Clarendon Laboratory a Hertz radiator to which he connected an ordinary induction coil controlled by a Morse key. In the Museum Lecture Room he then installed his receiver consisting of a replica of the Hertz radiator. But, in this case, it was connected to a voltaic battery and a sensitive 'coherer' detector fitted with an ingenious device for automatically tapping the detector to restore it to its original state after it had operated; at the same time, the tapper was arranged to operate a recorder. By this means he demonstrated that, when the transmitter Morse key in the Clarendon Laboratory was depressed, it caused a mark to be made on the receiver Morse recorder in the Museum Lecture Room.

This is the earliest recorded instance of the transmission and reception of a signal by Hertzian waves and it is clearly of great historical importance. Nevertheless, as both Professor J. A. Fleming and Dr. J. Erskine-Murray go to some pains to point

out in their separate accounts of the lectures, on each occasion the possibilities of communication by telegraphy were not envisaged at the time by the lecturer. The physicist, Lord Rayleigh, having witnessed the demonstrations, commented in the discussion: 'If you follow that up, there is a life's work in it'. Lodge admitted later that Rayleigh was quite right, but he did not follow it up effectively as he was 'too busy with teaching work to take up telegraphy or any other development'.

These lectures, bringing home so forcibly the power of an electric spark to affect instruments at a distant place, must have turned the thoughts of many inventive individuals to its utilization as a means of communicating from place to place without interconnecting wires.

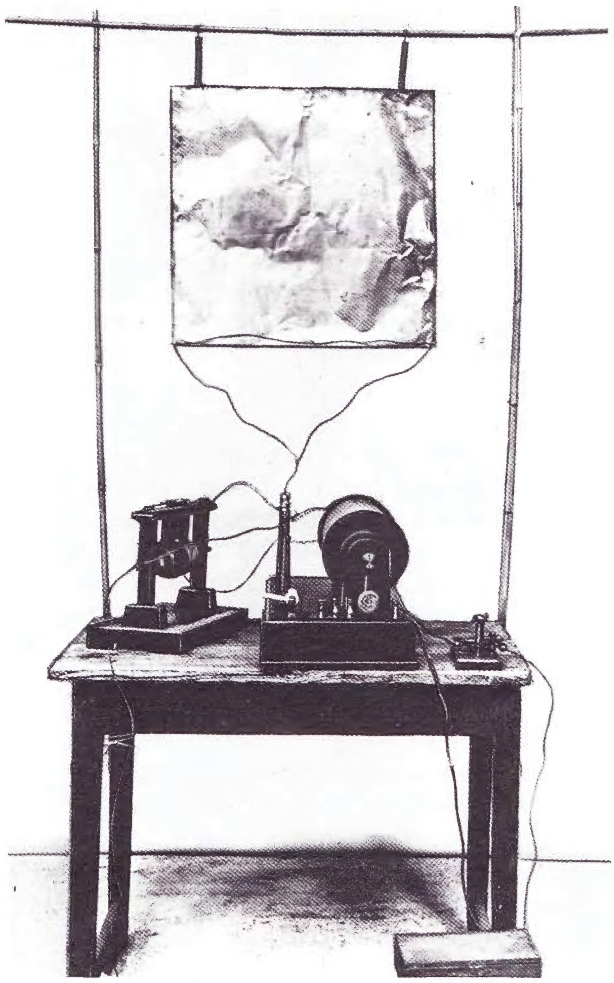
Enter Guglielmo Marconi

One such person was a young Italian from Bologna, Marconi. He had read about Hertz's work, and indeed the work of many scientists and engineers, and, at the tender age of twenty, he set up a laboratory in the Villa Grifone where he lived (fig. 1), and set to work with the avowed intention of establishing telegraphic communication without interconnecting wires. He showed remarkable ability and scientific insight in being able to see the defects in the apparatus of much older workers and very quickly appreciated the requirements for a practical system of electromagnetic telegraphy. In the first year of his work he experimented and improved upon the coherer detector, the induction coil and parabolic directional aerials.

By 1895, Marconi had completed his experimental apparatus (fig. 2). By incorporating an automatic tapper with his coherer and by adopting a raised aerial arrangement, he achieved a great increase in the distances over which he could transmit. The aerial consisted of a short length of wire at the end of which a zinc plate was attached; an earthed lead completed his apparatus. It is said that he was able to transmit over a distance of 1.5 miles by the end of 1895.

In that same year, Popov, of the Russian Navy Torpedo School at Kronstadt, had access to a good library with most of the foreign journals and books. These stimulated his interest in scientific research, particularly in the work of Hertz, whose experiments he was able to repeat. He was also greatly impressed on reading the lecture and description of experiments given by Oliver Lodge in 1894. He very quickly duplicated Lodge's receiving apparatus and installed it at a meteorological observatory. There he connected it to a lightning

1 *The Villa Grifone. Marconi is buried in the mausoleum shown in the foreground.*



2 *A replica of Marconi's transmitter which he used in experiments in Italy in 1894*

conductor and used it to record lightning occurring at a distance of up to 20 miles away.

Popov's receiving apparatus was described in the St. Petersburg Physical Society Journal in January 1896 simply as a lightning recorder. It is highly probable that neither Marconi nor Popov was aware of the near-parallel experiments being conducted independently by the other.

In 1895, Capt. H. B. Jackson of the Royal Navy succeeded in exchanging messages by Morse code between two warships using induction apparatus that he devised himself. This was good enough to be employed on some of H.M. ships but was ultimately replaced by Marconi's equipment. When Jackson and Marconi met they treated each other with friendship and respect.

Unrelated Events

An account of the development of wireless telegraphy would not be complete without reference to a series of seemingly unrelated events which occurred prior to the advent of wireless. All of these are worthy of mention because they provide the background against which the scientists and engineers achieved their great objective of wire-less communication.

The exact date at which the first observations of electrical phenomena were made, excepting the cave-man's observations of lightning, is really unknown, but they are usually attributed to Thales, a Greek, born at Miletus in the year 640 BC He is said to have noticed that amber, when rubbed, had the power of attracting light objects such as dry hair on a man's head. The Greek word for amber was 'elektron' from which springs our modern words electricity, electron, electro, etc.

No more appears to have been discovered about electricity until Gilbert found, in about 1600, that many other substances had the power to attract light objects when they were electrified by friction. Gilbert wrote a book on 'Magnetism and Attraction Between Bodies'. This was probably the first book dealing with electrical phenomena to have been written. Practically all our electrical knowledge has been acquired since that date.

The first glimmering of telegraphy by wires came in 1795 in a paper by Prof. Salva, an eminent Spanish physicist and inventor, entitled 'On the Application of Electricity to Telegraphy' and read before the Academy of Sciences, Barcelona. At one point Salva said:

'One could, for example, arrange at Mallorca an area of earth charged with electricity and at Alicante a similar space charged with the opposite electricity with a wire going to, and dipping into, the sea. On leading another wire from the seashore to the electrified spot at Mallorca the communication between the two charged surfaces would be complete, for the electric fluid would traverse the sea, which is an excellent conductor, and indicate by the spark the desired signal.'

Small wonder that Fahie[1] described this as a 'bizarre passage' and, although seriously meant 'cannot be regarded as more than a happy inspiration of genius'.

Although not of great importance in the present context, the year 1899 must be regarded as highly significant for the British public, for it saw the inauguration of the first public service of domestic electricity.

Wheatstone and Cook, two engineers who played a prominent part in telegraphic communication, patented the first wired telegraphic system in 1837. The advent of wired telegraphy was an event which was to open up amazing opportunities for communication throughout the world. The first wired telegraph route in Great Britain was laid between Euston and Camden Town on the London and Birmingham Railway.

From the earliest days of electric telegraphy, inventors had their attention directed to the problem of dispensing in part, or entirely, with continuous interconnecting wires. In 1836 Stenheil of Munich, acting on a suggestion by Gauss, carried out a test in wired telegraphy, between Nuremburg and Fürth, in an endeavour to use the railway lines in the place of properly insulated telegraph wires. The test proved a failure, but it led to a most important discovery. Rightly attributing failure of the experiment to leakage of electricity through the earth between the rails, the idea occurred to him that, because the earth appeared to be so good a conductor of electricity, it might possibly be employed in place of the return wire, which had been used up to that time. This experiment was tried and proved entirely successful, and it was undoubtedly an important contributions to successful telegraphic communication, not only for wired systems, but it probably also influenced the early adoption of the earth connection in the radiator for wireless.

The electric telegraph by metal conductors was destined to be the great competitor in the coming wireless telegraph war that was to be waged across the Atlantic Ocean.

The first transatlantic submarine cable, a milestone in telegraphic communication, was laid in 1858 after several mishaps during its installation. The project was sponsored by the Atlantic Telegraph Company, and was carried out by a joint Anglo-American team. The British supplied the

cable and a ship, HMS 'Agamemnon', while the Americans supplied a second ship, the USS 'Niagara'. The 'Niagara' laid the first half of the cable starting at Valentia Island, County Kerry, and the second half was laid by the 'Agamemnon', finishing up at Trinity Bay, Newfoundland.

Unfortunately, the triumph of this first cable was short-lived. From the very first message, the cable proved to be unreliable and much repetition of messages was necessary. It was soon obvious that the insulation was impaired and, as time went on, signals became more and more unintelligible. After two months of operation the cable went completely dead and all further attempts to bring it to life were useless.

Subsequently, the cable ship 'Great Eastern', constructed specifically for submarine cable laying, succeeded in laying a series of cables across the Atlantic Ocean between the years 1865 and 1874. These cables were, in the main, successful and remained in service without competition until Marconi bridged the Atlantic by wireless telegraphy some thirty years later. Even then it was a decade or so before it became a serious challenge to cable telegraphy.

While the last transatlantic cable was being laid in 1874, a baby boy was born in Bologna, Italy, to Giuseppe and Annie Marconi. He was christened Guglielmo. The world was to hear much of this baby and of the Villa Grifone, his father's villa, in which he spent much of his young life. From there he was to throw down a challenge to the cable companies which, by achieving telegraphic communication across the Atlantic Ocean even before he was born, had gained such a start over him.

As if to pave the way for the adult Marconi, the requirements for a wireless telegraph communication system were defined by Sir William Crookes in 1892, well before anyone had given serious thought to telegraphy without wires. Crookes allowed his trained scientific imagination to concern itself with the recent discoveries, and these prompted him to write a monumental article entitled 'On Some Possibilities of Electricity', which was published in the 'Fortnightly Review'. In this article he endeavoured to forecast some of the applications of high-frequency electric currents and of Hertzian waves. In his look into the future he clearly discerned the coming wireless telegraphy based on the application of Hertz's work. While there is no description of invention in the article there is much prognostication.

Dealing with electromagnetic waves and their properties Crookes wrote:

'Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence.'

'Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wavelength of which I have spoken will easily pierce such mediums which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables or any of our present costly appliances.'

'Granted a few reasonable postulates, the whole theory comes well within the realms of possible fulfilment. At the present time, experimentalists are able to generate electrical waves of any desired wavelength from a few feet upwards, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction. Also, an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and, by concerted signals, messages in the Morse Code can thus pass from one operator to another.'

'What therefore remains to be discovered is, first, simpler and more certain means of generating electrical rays of any desired wavelength, from the shortest, say, of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens of miles; second, more delicate receivers which will respond to wavelengths between certain defined limits and be silent to all others; third, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions, and fading away according to the law of inverse squares.'

'I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wavelengths of any preconceived length.'

'This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researchers which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact.'

Without question, Crookes must be given great credit for bringing together the five streams taken towards the development of wireless by laying

sound foundations for the final solution. He had been able to visualize vividly what was needed to be done so that, even twenty years later, his 'wireless specification' was still valid. Without doubt, his paper was read and noted by Branly, Preece, Lodge, Popov, Jackson and Marconi. From that point the great race to produce a workable system of 'wireless telegraphy' then commenced.

Four years later, on February 2nd 1896, young Marconi, still only twenty-two years old, came to England with the wireless transmitting and receiving apparatus which he had constructed (fig. 3). With this system he was able to demonstrate convincingly to the British Post Office, the Royal Navy and the Army that he could communicate over distances of more than a mile.

The Teenage Marconi

Annie Jameson was an Irish girl who eloped to marry Giuseppe Marconi, an Italian widower much older than herself. From their marriage, performed privately at Boulogne-sur-Mer in France, a son, Alfonso, was born. Nine years later, in 1874, a second son – Guglielmo – was born.

Although Guglielmo was born in Giuseppe's town house in Bologna in central Italy, his young life was mostly spent at the Villa Grifone, the family estate house at Pontecchio near Bologna.

From all accounts Guglielmo did not lead a very happy childhood, mainly on account of his father's uncompromising disposition, for, in his dour and unyielding way, he ruled his household in the style of a martinet. Because of his mother's English connections, Guglielmo spent much of his time away from home on visits to England and to English-speaking families in Italy; consequently, his education was very much neglected.

3 ***Marconi photographed shortly after his arrival in England from Italy in 1896 with his wireless apparatus***

By the time he was eventually sent to a school in Florence, he found it difficult to cope with the give-and-take in the classroom, or even to keep up academically with other children of his own age, many of whom made fun of his poor Italian accent. This unfortunate situation inevitably showed up in his character in that he was given to solitariness to a marked degree, so that even his parents failed to understand what was going on in his mind. Even at this early age he could be described as a 'loner'. He became self-sufficient and spent his spare time in reading scientific books and constructing ingenious mechanical and scientific devices without help or encouragement from his father.

It was a great disappointment to his father when Guglielmo failed to pass the entrance examination to the Italian Naval Academy. It was also a great disappointment to Guglielmo himself for he had developed a great liking for a seafaring career – a liking which almost amounted to an obsession which was to play a major part in his adult life. Guglielmo's father's anger knew no bounds, for he considered that the boy had dallied with his studies and had jeopardized his chances of a naval career.

Eventually, Guglielmo was entered into the Livorno Technical Institute and was happy at the prospect of receiving regular scientific training but, again, failure was to be his lot. His ambition at that time was to take up a recognized course leading to an electrical career, but he was even unable to pass his matriculation examination for entry to Bologna University.

Guglielmo's father became even more angry and even wrecked the devices that his son had constructed, and punished him by withholding the pocket money he was in the habit of receiving. Giuseppe was aghast that his son was nearly twenty years old and still, in his opinion, wasting his time and energy on aimless electrical experiments.

Guglielmo became more estranged from his father but, luckily, his mother – scarcely understanding what her son was doing – did all she could to encourage him to persevere in his efforts to make a career for himself in the electrical world. But, not properly understanding where the boy was heading, she went in desperation to Professor Righi, a professor at Bologna University and a near-neighbour of the Marconis, and begged him to allow Guglielmo to attend the laboratory classes he gave in the Department of Physics.

Righi was at that time intensely interested in the production and study of Hertzian waves and had himself contributed much original scientific work

on the subject. The knowledge that he imparted to Guglielmo must have done more than anything else to mould the young man's activities which were to become a life-long obsession.

Under the guidance of Righi, young Guglielmo, throughout the winter of 1894 and the following spring, read in the University library all he could find about Hertz's work and the extension of it carried out by Lodge in his seminal lecture of 1894 in commemoration of Hertz's work. It is doubtful whether he had the basic knowledge to understand all that he read, but there and then he dedicated himself to produce apparatus by which intelligence could be conveyed between two places by an electrical system, without the aid of interconnecting wires.

In the seclusion of his attic laboratory at Villa Grifone, the seeds of an invention that would soon become the topic of conversation the world over were sown.

In this great task, Guglielmo had the benefit of the description of all the ingredients that Sir William Crookes named in his 'wireless specification' of 1892. He had also the scientific treatises of Maxwell and Faraday; the experimental work of Hertz and Lodge. He had seen the spark generator of Ruhmkorff, the Leyden Jar condenser, the coherer detector of Varley, Calzetti Onesti, Branly and Lodge, – all the components which must have been in daily use in Righi's laboratory at the University. He had also read, no doubt, of the loaded vertical aerial and earthed connection, patented by Dolbear in 1882.

What Guglielmo had to do was to improve upon those components and piece them together. His indomitable will, his intuitive mind and nimble fingers very quickly enabled him to construct his first workable system.

Very soon the distances over which he was able to transmit exceeded the space available in his attic laboratory. In order to test his system to the limit he took his apparatus out into the spacious grounds of the Villa Grifone. He then made the important discovery that, as he lengthened his vertical aerial wires, so the distances over which he could communicate increased notably. It is doubtful if at that stage he understood that, by lengthening his aerial, he was automatically increasing the length of his electromagnetic wave. It was soon to be found out that the longer the wavelength, the greater the ease with which it was possible to surmount obstacles such as hills.

Guglielmo was now ready to demonstrate his wireless communication system.

The Adult Marconi

By September of 1895, at the age of 21, Marconi had progressed to such an extent that he was able to inform the Italian Government, through friends in official quarters, that he had engineered an electrical system for wire-less communication, which had a range at that time of well over a mile. He offered this to the Italian Government for further development. It was a great disappointment when the offer was summarily refused without even further investigation.

Marconi's mother still had complete faith in her son, and what he had already achieved, although she understood little of the real implications. In February 1896 she made up her mind that England offered a better chance for her son's career. Mother and son subsequently set out on what turned out to be an historic journey to London.

With the help of relations and friends they eventually found accommodation in Hereford Road, Bayswater. They were particularly fortunate in having the cousin of Guglielmo, Henry Jameson-Davis, available to familiarize the young Marconi with his new surroundings.

It was from Hereford Road that Marconi and his mother set about writing the provisional specification for the patent covering his wireless communication system. This task was completed in a few months and, on June 2nd 1896, the documents were officially deposited in the London Patent Office. On July 2nd 1897, British Patent No. 12 039 was granted[(2)]. This was the first patent granted in the world in connection with wireless telegraph communication using electromagnetic waves, as demonstrated by Hertz.

Marconi thereby secured unto himself the credit, and indeed the honour, of being first in the field of true wireless telegraphic invention. Circuit diagrams of his apparatus are shown in our previous issue[(3)].

Marconi's next task was to gain access to influential people to whom he could demonstrate his communication system. By good fortune again, Henry Jameson-Davis moved in a circle of scientific friends, one of whom was Alan Campbell Swinton who was well-known for his own researches. Campbell Swinton undertook to effect an introduction to William Henry Preece, the Engineer-in-Chief of the British Post Office.

As described earlier, Preece himself was not uninformed on matters concerning communication, but, unlike Marconi, he had not appreciated the advantage to be gained by using Hertz's

electromagnetic wave system. At the demonstration that took place following the introduction, Preece was very impressed and immediately decided that the Post Office must participate in Marconi's work.

In the days ahead, Preece became Marconi's staunch supporter. He offered Marconi the use of his own laboratory where he had been searching for the answer that Marconi seemed to have found; he even allowed Marconi to annex one of his most valuable assistants, George Stephen Kemp, who was to become Marconi's first and most loyal assistant.

The first demonstration took place between the Post Office in St. Martins-Le-Grand and the Savings Bank in Queen Victoria Street. It was completely successful and Preece urged Marconi to carry out further tests across Salisbury Plain. For these tests, a bungalow called 'Hillcrest', on the A30 road was chosen in which to install the fixed transmitting apparatus. The receiver was carried on a vehicle supplied by the Army. The modern equivalent, the 'Scimitar' military transceiver, is shown in fig. 4.

Marconi said that he used parabolic reflectors and resonators operating on a wavelength of 30 centimetres. Later in the tests, elevated aerials operating on a much longer wavelength were used and, as Marconi had already observed in Italy, much greater distances were achieved by so doing. Thereafter, the parabolic reflectors were consigned to the scrap-heap, where they were to stay for over thirty years.

4 *Scimitar H Manpack, in use, in tactical setting*

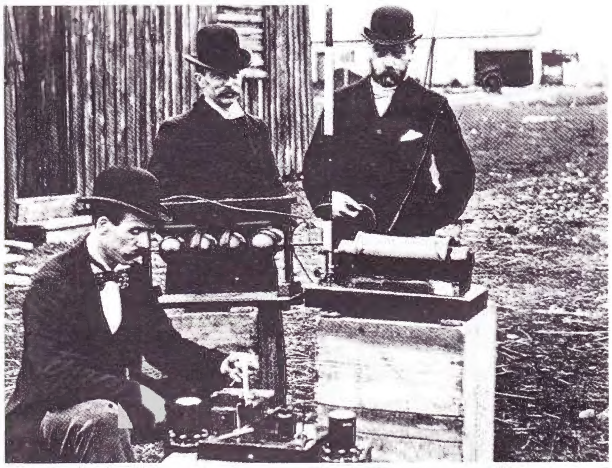
The tests on Salisbury Plain – and later across the Bristol Channel (fig. 5) – continued throughout the summer and autumn of 1896, and the range of communication increased to nine miles. Preece of the Post Office, Capt. Kennedy of the Royal Engineers, and representatives of the Royal Navy were very impressed with the possibilities of the technique that Marconi, just turned 22 years of age, had demonstrated to them. Further tests were therefore planned on a much more ambitious scale.

Preece, in particular, was by then sure that in his own experiments he had been investigating the wrong system in his attachment to the induction method of transmission. He magnanimously paid tribute to Marconi in a lecture he gave to the Royal Institution in 1897[4], saying:

'He (Marconi) has not discovered any new rays, his receiver is based on Branly's coherer...but he has produced a new electric eye, more delicate than any known instrument, and a new system of telegraphy that will reach places hitherto inaccessible....'

This tribute effectively staved off the scurrilous criticism of a disbelieving scientific world and a somewhat hostile press. Lord Kelvin, later to be a close friend of Marconi, was one of the early doubters. 'Wireless' he is said to have snorted 'is all very well, but I'd rather send a message by a boy on a pony'.

Throughout this period, Marconi maintained a quiet and dignified modesty when other young men of his age in similar circumstances might have been forgiven for becoming conceited. He is



5 *Post Office engineers examining Marconi apparatus during tests made across the Bristol Channel in 1897*

very accurately described by H. J. W. Dam of the Strand Magazine after an interview in 1897, a description which was true for much of Marconi's life. Dam wrote:

'He is a tall, slender young man, who looks at least thirty and has a calm, serious manner and a grave precision of speech which further gives the idea of many more years than are his. He is completely modest, makes no claims whatever as a scientist, and simply says that he has observed certain facts and invented instruments to meet them.'

In the same interview Marconi told Dam:

'I do not wish to be recorded as saying that anything can actually be done beyond what I have already been able to do.'

There is little doubt that Dam must have remembered what he had written about Marconi when the world heard that Marconi claimed to have succeeded in receiving signals across the Atlantic Ocean, a claim that was doubted by many for some seventy years.

A lifelong characteristic of Marconi was his willingness to recognize the contribution made to the art of wireless by other workers in the field. A typical example can be found in his discourse delivered to the Royal Institution in 1900[5]. He opened by calling attention to those workers saying:

'When Ampère threw out the suggestion that the theory of universal space possessed of merely mechanical properties might supply the means for explaining electrical facts, which view was upheld by Joseph Henry and Faraday, the veil of mystery which had enveloped electricity began to lift. When, in 1864 Maxwell published his splendid dynamical theory of the electromagnetic field and devised the theory of space waves, and Hertz had proved experimentally the correctness of Maxwell's hypothesis, we obtained, if I may use the words of Professor J. A. Fleming, the greatest insight into the hidden mechanism of nature which has yet been made by the intellect of man.'

'We cannot pay too high a tribute to the genius of Heinrich Hertz who worked patiently and persistently in a new field of experimental physics, and made what has been called the greatest discovery in electrical science in the latter half of the nineteenth century. He not only brought about a great triumph in the field of theoretical physics but, by proving Maxwell's mathematical hypothesis, he accomplished a great triumph in the progress of our knowledge of physical agents and physical laws.'

'The experimental proof of Hertz, thirteen years ago, of the identity of light and electricity, and the knowledge of how to produce and how to detect these space waves, the existence of which had been so far unknown, made possible true wireless telegraphy.'

A great man paying tribute to other great men! This was the very young man who already walked in high places, the young man who did not claim to be a scientist, and who had not yet attained his 26th birthday. This was the young man who had pitted his brains and his faith against scientists and engineers two and three times his age and, without scientific help, had emerged head and shoulders above the best men the world could produce.

By 1897, Marconi was fully committed to what Lord Rayleigh had described as a 'lifetime' with his wireless. He was now in need of help, both financial and physical. A company was therefore formed, called 'The Wireless Telegraph and Signal Co. Ltd.' with none other than Henry Jameson Davis as Managing Director. Very soon, at father Giuseppe's urgent request, this Company was called 'Marconi's Wireless Telegraph Co. Ltd.'

The Mature Marconi

What kind of man did Marconi turn out to be in his later years? What was his standing amongst the men who worked closely with him, his friends and the great men of science? More interesting than all, possibly, what was his standing in the minds of the people of the world?

Most people when they first met Marconi were struck immediately by his immaculate appearance, and then became intrigued by his unsmiling and shy – almost aloof – demeanour, and his serious and precise manner of speaking – just as Dam described him in 1897.

Notwithstanding his Italian/Scotch/Irish ancestry, he gave the impression that he was a man who would remain unflappable and calm even under the greatest strain. He spoke and wrote the English and Italian languages fluently and, in consequence, he was in great demand as a lecturer, writer and after-dinner speaker.

Marconi's assistants found him a good chief to work for, provided one quickly came to terms with the idea that one was expected to be on duty twenty-four hours a day, seven days a week. He certainly drove his assistants hard, but never so hard as he drove himself. He was always most polite to them and had the rather flattering habit of addressing them as Mr. So-and-So. They, for their part, always called him 'Sir', but amongst themselves they respectfully referred to him as 'G. M.'

There was the occasion when the writer had arranged to get married and with great temerity plucked up the courage to say on the Wednesday: 'Please Sir, may I go back to England to get

married on Saturday?' 'Yes', replied Marconi, 'but be sure you are back by Monday'. He was back by Monday!

A most remarkable characteristic of Marconi was his ability to think big and persuade others to think big with him. Most of his outstanding experiments were carried out in later years on the most grandiose scale that probably, in this day and age, would not be considered economically prudent. But such was his fanatical obsession with 'his wireless', that he brushed aside such mundane considerations as cost-effectiveness as of little consequence. He had a remarkable gift of inventiveness and experimentation together with an intuitive insight into the causes of failure in a particular line of investigation, and what to do to remedy the defect. He had, in fact, what one might call 'wireless greenfingers.'

The fertility of Marconi's mind was a source of constant astonishment to those who worked with him. His imagination knew no bounds and he was able to forecast with uncanny accuracy the uses to which wireless, and wireless techniques, would one day be put – even up to two decades later.

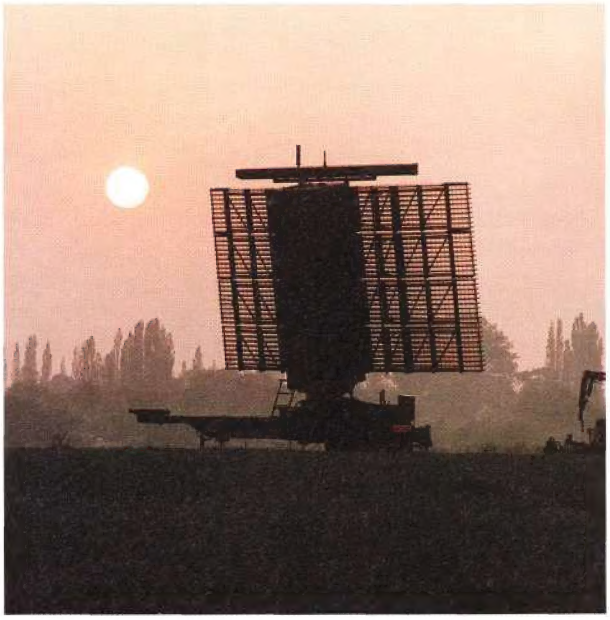
This prophetic ability was, for example, well illustrated when he read his paper to the joint IEE/IERE in New York in 1922[(6)], where he described how radar would one day be made to work. In fact, radar was developed in 1935 (a sophisticated modern equivalent, the solid state Martello three-dimensional radar system, is shown in fig. 6). Again, in a paper he read in 1930 at Trento, Italy, he forecast the part that wireless would one day play in the fields of radio astronomy, radio meteorology and extra-terrestrial communication.

In connection with extra-terrestrial communication, Marconi was convinced that life of some kind must exist on some of the other planets in the universe and – perhaps – the 'inhabitants' might be trying to communicate with our Earth by the same kind of wireless waves that 'Earthmen' were using. On Marconi's instructions, a regular listening schedule was initiated in 1931. What kind of signal did he expect to hear? 'Listen for a regularly repeated signal' said Marconi. The tests, needless to say, gave a negative result – the receivers and ancillary apparatus at that time were far too insensitive. What a near miss though! Pulsars were subsequently observed by radio astronomers in 1967.

A few months before his death in 1937, Marconi forecast that television would one day be transmitted by wireless across the Atlantic Ocean – it was in fact achieved via the satellite 'Telstar' in 1962.

After his wireless, the sea was Marconi's great love, and most of his early work was expressly carried out with the aim of keeping ships at sea constantly in touch with each other, and with their shore bases (fig. 7).

In 1919 he acquired the 700 ton steam yacht 'Rovenska', built in Scotland for the Archduchess Maria Theresa of Austria. The S.Y. 'Rovenska' had been requisitioned by the British Admiralty to serve as a wartime minesweeper. Marconi re-christened the vessel S.Y. 'Elettra' (fig. 8 and also see the painting on the front cover); he gave the same name to his third daughter, who was born in 1930. Sadly, fate turned full circle, subsequently, when the S.Y. 'Elettra' was requisitioned by the Germans, again for duties as a minesweeper; she was sunk by Allied Air Forces in 1944 off Zara in the Adriatic.



6 *The Martello three-dimensional air defence radar*

7 *Marconi (4th from right) demonstrating wireless apparatus to Italian officials at Spezia in 1897*

8 Marconi's steam yacht 'Elettra'

9 Marchese Guglielmo and Marchesa Cristina Marconi, 1933

Without doubt, the happiest moments of Marconi's life were when he could bring together his love of the sea, his love of his wireless and the love of his family.

Not only was Marconi the pioneer and inventor of a wireless communication system, he was also a man of many other callings. He was as accomplished at the piano as he was at his wireless Morse key. The writer recalls the occasion when Marconi was operating his Morse key with his impeccable Morse characters and having to listen to a correspondent whose Morse was far from being impeccable; eventually his patience was exhausted and he asked his correspondent if that was the best Morse he could send. 'Yes', said the correspondent, 'it is the best I can do'. 'Well', replied Marconi, 'try using the other foot!'

He turned out to be a shrewd business-man, a skilful negotiator and a good administrator. He was a Parliamentarian, having been nominated to the Italian Senate when he was only 30 years old. As a statesman, he represented Italy at the signing of the Versailles Treaty after the first World War.

How did he stand with the men of science? There is no doubt that he was feared by those who had interests in the telegraph cables, particularly the submarine cables spanning the Atlantic Ocean. He was idolized by many and disliked by a few. Professor Sylvanus Thompson among the latter had this to say about him in 1902, following Marconi's successful bridging of the Atlantic:

'This young scientist's precocious reputation will be likely to end in a fizzle'.

Probably most important of all, how did the world in general receive Marconi? He numbered Kings, Queens and Heads of State amongst his friends. King George V conferred on him the Knight Grand Cross of the Royal Victorian Order in 1914. From all parts of the world, twenty-four other honours were bestowed on him. He acquired fifteen honorary Doctorates from world universities, although he himself had no academic qualifications in his own right.

He was appointed President of the Italian Royal Academy in 1930 and nominated President of the Italian National Council for Research; he was associated with thirty other scientific institutions.

Marconi received thirty-two major awards, including the Nobel Prize for Physics jointly with Professor Braun in 1909. Fifty major scientific papers on the subject of wireless exist in the name of Marconi, and 2 500 articles have been published by the lay and scientific press.

Such, then, was Marconi's standing in the world of science, and yet he himself was not a scientist – a fact which he seemed to take great delight in proclaiming.

This can certainly be said of Marconi – if an engineer can be defined as one who utilizes and controls the energies of Nature for the convenience and benefit of mankind, then Marconi was an 'engineer' worthy of the highest traditions.

As befitting such a man, the King of Italy marked his country's gratitude for the honour that Marconi had brought to Italy by conferring upon him the hereditary title of Marchese, in 1928 (fig.9).

In the evening of July 20th 1937, the day on which the great pioneer and inventor passed away, every wireless station in the world ceased to operate for two minutes. Could the world have paid a greater tribute to the man known as Marconi?

(Part II of this paper will appear in the next issue of the GEC REVIEW, Vol. 7, No. 2, and will cover some of the highlights of Marconi's career, including transmission across the Atlantic, the saving of 700 lives after the 'Titanic' disaster, and blind navigation using microwaves)

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Guglielmo Marconi and the History of Radio – Part II

by G. A. Isted, M.I.E.E.
Personal Technical Assistant to G. Marconi, 1926 – 1936

G. A. Isted was born in 1903 and joined the Marconi Company at Chelmsford in 1923. In 1926 he was transferred to G. Marconi's private laboratory in London. In 1929 he was sent to Italy as Marconi's personal technical assistant and participated in Marconi's microwave experiment. When hostilities broke out between Italy and Abyssinia in 1935, he was recalled to England where he joined the staff of T. L. Eckersley who was studying radio wave propagation, mostly at Gt. Baddow. During World War II, he was in charge of the RAF section of the Inter-Services Ionospheric Bureau based at Great Baddow. Subsequent to Eckersley's retirement, he became Chief of the Marconi Radio-wave Propagation Group. He was largely responsible for the success of the nationwide coverage of the Independent Television Authority Band III television service. He retired in 1969 after 46 years with the Marconi Company.

In Part I of this paper (GEC Review Vol. 7, No. 1) the early history of radio was outlined, along with Guglielmo Marconi's crucial pioneering rôle. Part II now covers highlights of his subsequent career, including transmission across the Atlantic, the saving of 700 lives after the 'Titanic' disaster, and blind navigation using microwaves.

Highlights of Marconi's Career

In every person's career there are episodes which stand out in one's mind like milestones along a road. Marconi had an abundance of them and it certainly would have been difficult, even for one who has studied his work in detail, to single out those which were more important than the rest.

If Marconi himself had been asked to name just four of his many achievements that gave him the greatest satisfaction, he would undoubtedly name as his first choice his epic experiment in which he first succeeded in receiving wireless signals across the Atlantic Ocean in 1901. The next would be the part that his wireless played in saving the lives of 700 survivors from the S.S. 'Titanic' disaster in 1912. His discovery of the daylight short wave in 1923 would have been a must. His final choice would have been his last large-scale experiment carried out in the Mediterranean in 1934 when, with the aid of microwaves, he was able to demonstrate that a ship could be manœuvred into port in conditions of zero visibility.

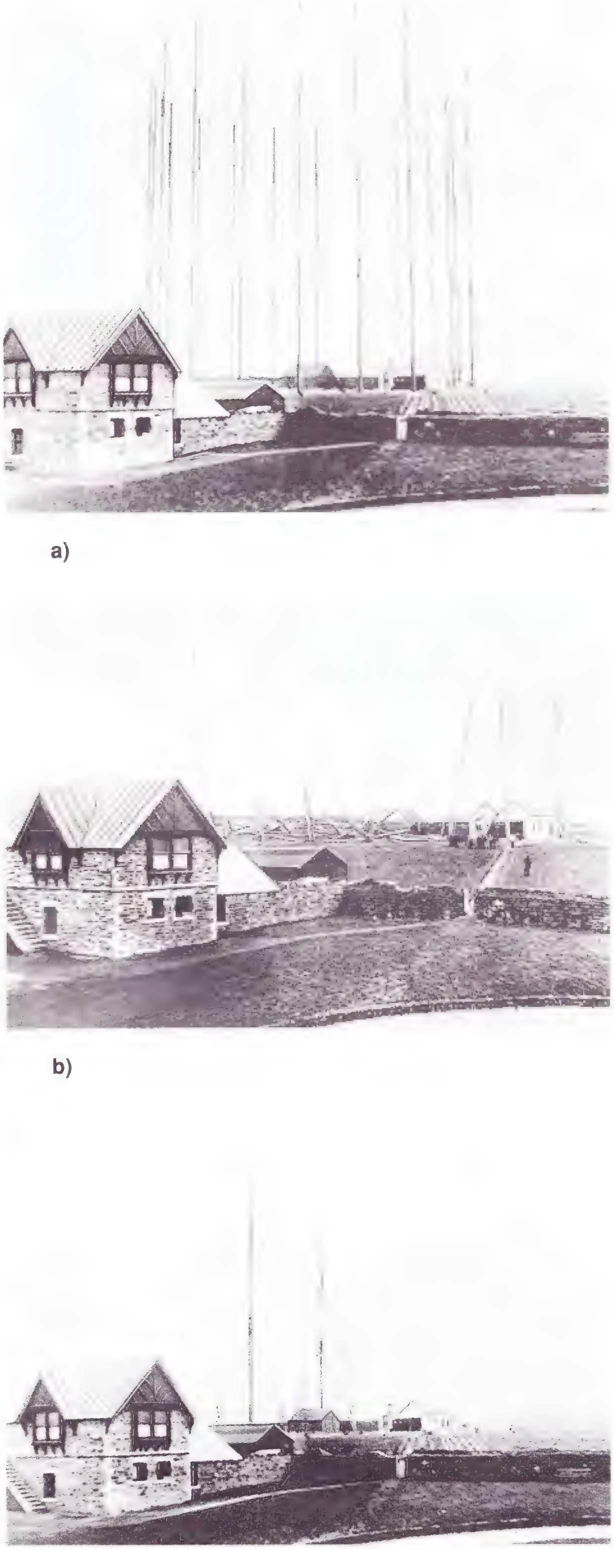
Transmission Across the Atlantic

Marconi's tests in 1900 had not indicated that there was any limit to the distance that wireless waves could be transmitted; the limit always seemed to be dictated by restrictions imposed by his apparatus. Characteristically, therefore, he thought big and decided to build the largest power-house spark transmitter (25 kW input power), with a view to establishing exactly what the limit was – if there was, in fact, a limit.

Professor J. A. Fleming was engaged in early 1900, to design and build this colossus, which was to be installed at Poldhu on the south coast of Cornwall. From here, various places at differing distances could be chosen where observations would be made (figs. 1a–c). The transmitter was operating in the spring and summer of 1901 and it was quickly found that strong signals were received at Crookhaven, South Ireland, 250 miles from Poldhu in spite of the intervening bulge of the Earth. Marconi reasoned that if signals were strong at 250 miles, there seemed to be nothing to stop the transmission of wireless waves across the Atlantic Ocean – after all, it was a little less than ten times the distance already covered!

In spite of protests from the Board of his Company and the derisory comments from 'the men who knew' that such a thing was impossible, Marconi embarked on the S.S. 'Sardinian', with his assistants Kemp and Paget, and sailed for St. John's, Newfoundland. Upon arrival, they housed themselves in a disused military hospital on top of the highest hill and set about assembling their receiving apparatus. In the end, because of equipment difficulties, the receiver was modified into the simplest arrangement possible. It consisted of a long wire held aloft by a kite as an aerial (fig. 2); the aerial was connected to a coherer and a pair of headphones and, finally, to an earth connection. What wavelength was used no one seems to know. Professor Fleming admitted he did not know. It was not until 1905 that he developed a device for measuring wavelength which he called a cymometer.

Marconi's presence at St. Johns aroused much interest and journalists and sightseers were there in plenty (fig. 3). After a period of listening there came the day, December 12th, when, at 1.30 p.m. Marconi was convinced that he heard the pre-arranged signal, three dots forming the Morse letter 'S', repeated. Kemp, his assistant, was also convinced that he heard the signal. Transatlantic



a)

b)

c)

1 a) ***The circular antenna array at Poldhu for the transatlantic test. This was blown down in a gale in September 1901. The array comprised wire and 20 wooden masts, each 200ft high.*** b) ***View of the antenna at Poldhu after the gale, and*** c) ***Poldhu wireless station in December 1901, showing the antenna system used for sending the first wireless signals across the Atlantic from England to Newfoundland***

2 ***Raising a kite at St. Johns, Newfoundland, in December 1901 for the first transatlantic wireless experiments. Marconi is on the extreme left.***

3 ***Marconi at St. Johns', Newfoundland, in December 1901 with the apparatus used to receive the first wireless signal across the Atlantic from Poldhu, Cornwall***

communication had been achieved by wireless telegraphy for the first time!

Why send only the letter 'S' – just three dots? According to Marconi, if dashes had also been sent, the dynamo supplying the power at Poldhu would have disintegrated under the increased load!

When news of Marconi's success appeared in the world press, it caused a major stir. Many people were excited at the prospects it offered but others, especially 'the men who knew', thought that Marconi was mistaken. It just could not be true, they said.

The arguments have raged ever since. Did Marconi hear three dots or didn't he? So far as Marconi was concerned he proved – two months later, during trials on the S.S. 'Philadelphia' across the Atlantic – that signals could be heard and recorded at comparable distances. The tape records of these trials were signed by the ship's captain as evidence of their authenticity.

A further question that raised doubts at the time was: why did not Marconi repeat the test the next day? The answer to that is simple. The

Anglo-American Telegraph Co. issued a writ prohibiting Marconi from carrying out further tests! They were in no doubt about the authenticity of the achievement.

At the Marconi Centenary Celebrations held at the Institute of Electrical Engineers in 1974, J. A. Ratcliff described(1) how he and a body of radio scientists and mathematicians had recently re-examined the conditions of the tests and had come to the conclusion that Marconi had not deluded himself on that day in 1901 – it all depended upon which wavelength was considered. This was seventy-three years after the event!

The rank and file of the Cable Company obviously took the news of Marconi's success not too seriously as the following light-hearted exchange of signals at Christmas, 1901, clearly indicated.

Christmas greeting from the cable terminal at North Sydney to its companion terminal at Liverpool:

Best Christmas greetings from North Sydney,
Hope you are sound in heart and kidney,
Next year will find us quite unable
To exchange over the cable.
Marconi will our finish see,
The Cable Co's have ceased to be,
No further need of automatics
Retards, resistances and statics.
I'll then across the ether sea
Waft Christmas greetings unto thee.

Reply from Liverpool to North Sydney:

Don't be alarmed, the Cable Co's
Will not be dead as you suppose.
Marconi may have been deceived,
In what he firmly has believed.
But be it so, or be it not,
The cable routes won't be forgot.
His speed will never equal ours,
Where we take minutes, he'll want hours.
Besides, his poor weak undulations
Must be confined to their own stations.
This is for him to overcome,
Before we're sent to our long home.
Don't be alarmed, my worthy friend,
Full many a year precedes our end.

And again from North Sydney to Liverpool:

Thanks old man, for the soothing balm,
Which makes me resolute and calm.
I do not feel the least alarm,
The signal S can do no harm,
It might mean sell to anxious sellers,
It may mean sold to other fellers.
Whether it is sold or simply sell,
Marconi's S may go to – well!

It is not difficult to imagine Marconi's elation at his success, and throughout his career he kept that episode well in mind as the greatest instance when the wise men who 'knew' based their reasoning upon inadequate data.

Thomas Edison was one of the famous scientists who believed that Marconi had successfully received wireless waves across the Atlantic Ocean and, when the American Institution of Electrical Engineers provided a banquet in Marconi's honour at the Wardorf Astoria Hotel, New York, on January 13th 1902, he sent the following telegram:

'I am sorry that I am prevented from attending your dinner tonight especially as I should like to pay my respects to Marconi, the young man who had the monumental audacity to attempt and succeed in jumping an electric wave clear across the Atlantic Ocean.'

There was fierce competition between the wireless and cable communication interests during the following years. With Marconi's introduction of the short-wave beam system, wireless started to prevail. Ultimately, however, they were merged sensibly into a new company calling itself 'Cables and Wireless Ltd.', in 1929.

A modern satellite communication dish, supplied by GEC-Marconi Communications Ltd. to Cable and Wireless p.l.c. is shown in fig. 4.

The Titanic Disaster

The first life-saving possibilities of wireless were demonstrated in 1899 when a wireless message was received from the East Goodwin lightship – which had recently been equipped with Marconi wireless apparatus – that she had been rammed

4 ***Mercury Communications Systems satellite communications ground station at Whitehill, Oxfordshire, for which Marconi has supplied antennas and electronic equipment as prime contractor***

during dense fog by the steamship 'R.F. Matthews'. A request was made for the assistance of a life-boat.

In 1911, McLaren and Battle gave a lecture to the Institute of Marine Engineers on the subject of Wireless Telegraphy at sea[(2)]. They stated at one point:

> 'As regards marine engineers who are going to sea, the presence of the Marconi apparatus gives us a certain amount of confidence in our work of taking charge of ships away from home. We feel that with the Marconi on board we are safe. It has become an important part to the life-saving service.'

Within a year how true that was going to be! McLaren and Battle continued:

> 'This has been demonstrated by the following announcement which recently appeared in "Telegraph and Telephone Age" : "A rough calculation has been made recently as to the success and value of assistance rendered by wireless telegraph to ships at sea in the saving of life and it is estimated that 3 000 persons owe their continued existence at the present time to the help rendered by wireless telegraphy."

That was up to 1911! It is interesting to observe that, when they referred to the wireless apparatus, they called it 'the Marconi' in the foregoing excerpt.

By 1910, it was mandatory to have wireless telegraph apparatus installed on every large ship, with a competent telegraphist in attendance. Not all ships had enough telegraphists, or 'sparks' as they were collectively called, to cover a continuous twenty-four hour watch.

The need for more than one telegraphist was made crystal clear at the time of the White Star Line steamship 'Titanic' disaster. The 'Titanic', the pride of the British mercantile fleet, left Southampton on the morning of April 10th 1912, in perfect weather, on her maiden voyage across the Atlantic to the United States of America. Up to that time she was the largest ship ever to be built, having a displacement of 46 000 tons and extending 900 feet in length. She was not the fastest ship, but she was the most luxurious one the world had ever seen and could accommodate 2 000 passengers.

The 'Titanic' at the time of her launch was described as 'unsinkable'.

The ship carried two 'sparks'; Chief Telegraphist John Phillips and Second Telegraphist Harold Bride. Their wireless installation was the very latest in design and was one of the most powerful in those days, having a range of 350 miles by day and much more at night.

On Sunday, April 14th, as the 'Titanic' was approaching Cape Race, Bride received a wireless signal in the afternoon from the S.S. 'Californian' to say that icebergs had been sighted in the vicinity. The signal was passed to Captain Smith, the 'Titanic's captain, but for some reason which does not have a satisfactory explanation, he held the ship's speed, it is said, to 22 knots – icebergs or no icebergs. His ship was unsinkable.

Just before midnight, the passengers were singing and dancing with the bands playing after their good evening dinner; then the biggest maritime disaster up until that time befell the 'Titanic', but few at the time knew anything of it. There had been just the slightest jolt and the engines stopped. The 'Titanic' had struck an iceberg.

The only persons who really knew what had happened were those of the crew in No.10 stokehold who had seen the whole side of the ship torn apart beneath the water-line, followed by seawater cascading into the ship. Even Telegraphist Phillips, who was then on watch, was unaware that anything serious had happened and continued his routine work.

The Captain made his way to the wireless cabin and said 'We've struck an iceberg – send a wireless call for assistance'. This was thirty-five minutes after the iceberg was struck. Phillips tapped out the recognized Marconi distress call, CQD, followed by the 'Titanic's call-sign, MGY, and the message that an iceberg had been struck, and that assistance was urgently required. Subsequently he added the ships position as 41–46N, 50–14W. After a while, he included the internationally-recognized distress call, SOS, in his repeated calls.

Ships began to answer the call for help and themselves relayed the 'Titanic's call to those ships which had not received it directly.

The first to answer was a German ship, the 'Frankfort', which was about 150 miles away. Next came a call from a very small vessel, the 'Carpathia', having Marconi Telegraphist Cottam as the 'sparks'. She was about 60 miles away. She replied that she had turned about and was heading for the scene of the disaster at full speed. To steam at full speed in darkness knowing that icebergs were floating in the vicinity was a very risky procedure and the captain displayed great courage.

Other ships within wireless range – the 'Caronia', 'Virginian', 'Olympic', 'Baltic' and 'Birma' – all answered that they were steaming to the stricken vessel.

There was one ship, only 10 miles from the 'Titanic', which was large enough to have taken care of every person on board. She was hove-to because of the danger from floating ice. Her lights could be seen from the decks of the 'Titanic' but her wireless cabin was deserted, her wireless dead –

the single 'sparks' on board had gone to bed after a heavy day of operating. This was the same ship, the 'Californian', which had warned the 'Titanic' that icebergs had been sighted during the Sunday afternoon.

Meanwhile, Captain Smith knew that the Titanic could not keep afloat much longer and gave orders to abandon ship. As many lifeboats as could be launched were filled to capacity with scantily clad men, women and children, many of them injured, some were dying, and all were very wet and chilled in the ice-cold night air.

After a while the power failed on the 'Titanic' and the main wireless apparatus became useless. Phillips then operated the battery-driven emergency transmitter which enabled him to keep in contact with Cottam on the 'Carpathia' for some time. Cottam noted that, at 1.17 a.m., the 'Titanic' signals faded and abruptly stopped. The 'Titanic' was at the bottom of the sea, taking 1 500 souls with her.

Chief Telegraphist Phillips died by his wireless cabin, although he had been told by Captain Smith to save himself if he could. Telegraphist Bride had already gone over the side having done all he possibly could.

The little 'Carpathia' arrived at the scene a few hours later and in the dawn light located wreckage and then the lifeboats. She was able to rescue 700 survivors, thus preventing their deaths from exposure. Wireless telegraphy undoubtedly made the rescue possible.

Great confusion arose in New York because the wireless installation on the 'Carpathia' was unable to communicate directly with a shore station, but had to rely on his messages being relayed from ship to ship, and then to shore; inevitably, only exaggerated and distorted news reached its destination.

Telegraphist Bride had been rescued and, although he had been injured, made his way to the wireless cabin to help Telegraphist Cottam with his mammoth task of transmitting continuous news of survivors to the 'Olympic' for onward transmission to shore.

Marconi happened to be in New York when the disaster occurred and as soon as the 'Carpathia' docked with her human cargo, he immediately made his way to the wireless cabin to greet two tired men, Cottam and Bride. He was probably the first to obtain authentic news of the events which had, literally overnight, increased the 3 000 persons saved by wireless telegraphy, mentioned by McLaren in 1911, up to at least 3 700.

As Marconi came down the gang-plank to the quay he very humbly remarked: 'It is worthwhile having lived to have made it possible for these people to have been saved'.

That same day the newspapers bore headlines proclaiming that Marconi and his wireless had been the means by which 700 souls had been saved. In the House of Commons the Postmaster General, Herbert Samuel, in announcing the news of the disaster to a shocked House said: '.... That so many are alive today is due to one man, and one man alone, Mr. Marconi'.

The survivors themselves were moved to present Marconi with a gold medal, suitably inscribed by the noted sculptor, Poalo Trabetzkoz, as a measure of their gratitude for their deliverance.

The New York Electrical Society held a meeting on April 17th at which Marconi was asked to talk about 'The Progress of Wireless Telegraphy'. Such was the tumultuous reception he received that it was some time before he could begin to speak.

The 'Titanic' disaster threw into sharp relief the need for higher-powered transmitters so that no ship should feel isolated from shore. It also emphasized that some means must be found to avoid the 'Californian's calamitous silence. Marconi already had ideas of an automatic alarm apparatus which would alert the telegraphist to distress signals while he was on routine work or off duty. It was to be 1927 before it was mandatory to install such apparatus on ships.

The 'Titanic' disaster and the lives that were saved by wireless would surely have been one of the many milestones in Marconi's mind, for in 1932 he wrote:

'The greatest value of wireless, in my belief, is still demonstrated by its utility at sea.'

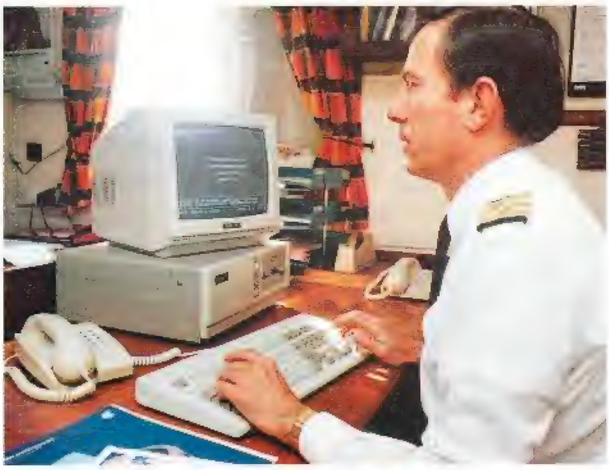
Fig. 5 shows modern marine communications equipment.

The 'Daylight' Short Wave Discovered, Mislaid, Rediscovered

In a survey paper which Marconi read to the American Institution of Electrical Engineers and the Institute of Radio Engineers at New York in June 1922, the title of which was simply 'Radio Telegraphy'(3), he said at one point:

'Some years ago, during the war, I could not help feeling that we had perhaps gotten rather into a rut by confining practically all our researches and tests to what I may term long waves, or waves of some thousands of feet in length, especially as I remembered that during my very early experiments, as far back as 1895 and 1896, I had obtained some promising results with waves not more than a few inches long'.

a)

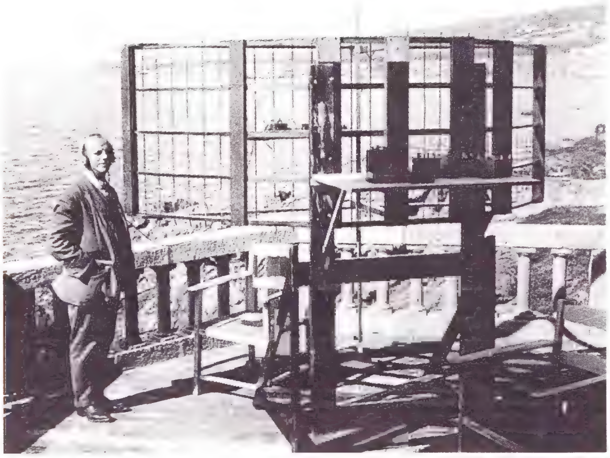


b)

5 ***a) Modern ship's radio room fitted with GEC-Marconi Communications Ltd. 'Oceanlink' series communications equipment, and* b) *radio operator using GEC-Marconi Communications Ltd. 'Oceanray 2' maritime satellite communication system***

This was probably a hint that he was working on ways and means for 'getting out of the rut', as he called it. In the paper he mentioned some tests which he and his assistant, C. S. Franklin, had carried out in Italy during the war. These were directed towards making a communication system that had a limited range, and which would be difficult for an unfriendly power to intercept. He described how, in 1916 (see fig. 6), he developed a spark system operating on a wavelength of 2 to 3 metres having a directional, or 'beam', aerial in just such a manner as Crookes described in 1892.

Marconi could very well have spoken about the short-wave experiments that had already been carried out the year before over the North Sea by Franklin but, typically, he chose to say nothing about this work because some very odd results were being obtained, which he could not explain.



6 ***C. S. Franklin in Italy in 1916 carrying out work on very short waves. This work led to the Marconi–Franklin short-wave beam system in the 1920s.***

These experiments had been carried out on wavelengths between 15 and 100 metres – very much shorter than the wavelengths then currently in use – across a series of routes between Zandvoort in Holland and Southwold, Hendon and Birmingham in England. It is now known that it would be difficult to imagine a more complicated and unpromising network of test routes over which to study the behaviour of radio waves. The network comprised 'all sea' routes, 'all land' routes, and 'mixed land and sea' routes, each route having its unique mode of transmission over the surface of the earth and sea.

An unpublished report of Franklin's to the Marconi Technical Board summarized the results obtained. He described, in particular, a remarkable and unexplained difference in the behaviour of signals in the 30 – 60 metre band over the different routes. Quoting from the report, Franklin said:

> 'Whereas at Southwold, about 110 miles from Zandvoort, the signal at night is much greater than the day strength; at Birmingham, however, 282 miles from Zandvoort, the day strength appears normally to be greater than that at Southwold, while at night it is impossible to get any sign of the signals.'

Experience had shown in the past that signal strength on long-wave transmissions was greater at night. Here was a complete reversal of the behaviour of long waves. Something needed an explanation!

With our knowledge today there would be little doubt that the day signal at Birmingham from Zandvoort was being reflected downwards by the upper layers of the ionosphere.

Incredible as it may now seem, Marconi actually had the discovery of the 'daylight' wave within his

grasp in 1922 – but failed to recognize it as such! Notwithstanding Marconi's lack of appreciation of the evidence of the tests, it was to take him only a short time to rediscover this much wanted 'daylight' wave.

In May 1922, just before he read his paper in New York, Marconi arranged with Franklin to make a detailed and careful examination of the transmission characteristics of all waves between 15 and 100 metres at differing distances. The transmitting station was to be at the historic site of Poldhu in Cornwall. Marconi's steam yacht S.Y. 'Elettra' (see later) was to be equipped with suitable receivers. They agreed that, as it was relatively easy to construct a beam aerial for 97 metres and that until more apparatus became available, the tests would be limited to that wavelength.

In the summer of 1923, Marconi took the 'Elettra' on a cruise to the Cape Verde Islands, off the west coast of Africa. Anchored at San Vincenzo, a distance of 2 500 miles from Poldhu and an all-sea route, he commenced a series of listening and measuring tests. He found that, at that distance, the signal was much better than any signals he had received over a comparable distance from high-power long-wave transmitters.

Nevertheless, as with long waves, the signals disappeared during the daylight hours. However, Marconi observed that the signals lasted for a time after sunrise at Poldhu and that they became audible again before darkness came at the Cape Verde Islands. That observation led him to suspect that some new phenomenon was operating on the 97 metre wavelength.

At the end of a report to the Directors of the Company on the results of the S.Y. 'Elettra's receiving tests, dated 12th June, 1923, Marconi wrote: 'I have little doubt, however, that with our present knowledge, and with stations using only about 12 kW, it would be possible to maintain, daily, a 10 to 14 hours communication service between Europe and Brazil, and perhaps with the Argentine'.

Upon his return to England, Marconi arranged for a further series of experiments to test and compare the 97 metre signals with other wavelengths down to 30 metres.

In the meantime, Marconi persuaded the British Government that the Imperial Communications chain of long-wave stations which the Company was about to supply were really obsolete before they were installed, and that the short-wave technique was the most economical and efficient system to employ.

In September 1924, Marconi continued his short-wave experiments when he cruised in the 'Elettra' through the Mediterranean. At the coast of Syria the yacht was anchored in the harbour of Beirut, a distance of 2 400 miles from Poldhu, mostly over land. Throughout the listening schedules, the astonishing observation was made that the 32 metre signal was operating all the daylight hours. It was clear, therefore, that if the wavelength was changed daily from 97 metres to 32 metres, a near 24 hours communication circuit was possible.

When Marconi returned to England, he initiated a schedule of transmissions on 32 metres from Poldhu and requested reports of reception. Swiftly came back reports from Argentina, Brazil, Canada and the United States of America that, at the appropriate times the daylight signal was being well received. Australia at the antipodes reported 23 hours out of 24 of good signals.

During the ensuing tests, it was established that other short waves were superior to the 97 and 32 metre waves. Marconi had achieved his ambition and, as he would have said, he'd 'gotten wireless out of the rut'. It was now up to his manufacturing organization to exploit the new and revolutionary techniques.

Marconi's success with short waves had astonished the scientists who then became very busy trying to explain how these things were possible. It was E. V. Appleton who proved conclusively the existence of the ionosphere, as well as measuring its height. He identified two reflecting regions, the first he named the E-layer in 1924, and a higher region he found two years later which he named the F-layer. Marconi had outstripped 'the men who knew' once more!

By 1926, by the use of the new short-wave technique and with the great help of Franklin's 'beam' aerials, the first of the Empire chain of two-way telegraph stations came into being between England and Canada. This was followed by many others to all parts of the Empire, each capable of passing telegrams at the rate, normally, of one hundred words per minute.

Franklin's 'beam' aerials, being highly directional, eliminated the worst of the effects of interference from lightning storms; but there remained another serious problem peculiar to the use of short waves. Marconi observed at the very beginning of his short-wave experiments that the signal intensity was constantly varying. The effect was commonly called 'fading' and, as time went on, it became understood that it was caused by the signal arriving by more than one route. When these signal components arrived out of step, the resultant signal was caused to 'fade' or, in extreme cases, the signal components could cancel one-another out and introduce what operators

called a 'drop-out'. These drop-outs might last a fraction of a second, but when telegrams are being passed at one hundred words a minute it is a serious matter.

The odd thing about this fading was that two receivers spaced a short distance apart did not suffer from the effect simultaneously. There was in fact a 'space diversity'. An elaborate investigation into space diversity was carried out jointly by engineers of the Marconi Company and engineers of the B.B.C. in 1928–1930. The site chosen was on Lord Rayleigh's Estate at Terling, near Chelmsford. For the investigation, three receiving aerials were spaced one mile apart alongside the straight portion of the Witham Lane, in line with the United States station of Schenectady, which broadcast programmes on a wavelength of 21.96 metres. The signals from each aerial were combined on the centre site and the resultant signal was judged as to whether it was of sufficiently good quality to allow it to be rebroadcast. The results of the investigation were considered satisfactory, as the effects of fading were reduced to a minimum.

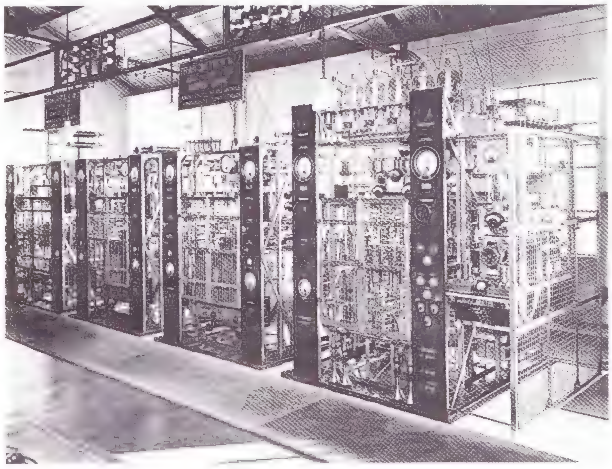
Marconi was also working on the problem of short-wave fading, but from a different point of view. He had observed that the fading was not coincidental on slightly differing wavelengths; this effect became known as 'frequency diversity'. In the seclusion of his private laboratory in Room 31, 3rd Floor, of Marconi House in London he set about designing a revolutionary system of communication. Marconi called it the Multiplex System. This system permitted three channels of communication – two telegraph and one telephony – to be superimposed onto a single transmitter. These three channels were separated at the receiver and transferred individually over land-lines to their respective destinations.

An ingenious method for the almost complete elimination of fading was employed for both telegraphy and telephony. The telegraph anti-fading device was based on the frequency diversity properties of short waves. The equivalent of sending the same message by two transmitting stations on two slightly different wavelengths was obtained by modulating the transmitter with frequencies of the order of 7 and 9 kHz, thus producing, side-bands of 14 and 18 kHz separation, respectively. At the receiver, these side-bands were separated and their respective channels recombined.

In the case of the telephone channel, situated between the upper and lower side-bands, the fading signal was used to operate a device called an 'automatic volume control', which maintained, by means of an electromechanical device, a constant level of signal to a telephone subscriber.

It has been said of Marconi that in all his experiments he 'thought big' – his Multiplex System of communication was a classic example that he actually did! The receiver had seventy-two valves, or 'tubes', housed in thirty double-screened copper boxes each having a capacity of three cubic feet, all supported on a massive angle iron frame weighing, in all, over a ton. The occupants of the floor beneath Room 31 heaved a sigh of relief when, finally, the day came for the receiver to be transported to its testing site at the Bridgwater beam station in Somerset (fig. 7)!

The system was put through its paces on March 1st 1929, when an important demonstration was staged between Bridgwater and Canada. It was witnessed by Sir Robert Donald, Chairman of the British Imperial Wireless Telegraph Committee,



a)

b)

7 **a)** ***Four panel short wave beam transmitter operating on 37 and 21 metres used for transmission to Egypt at the Dorchester beam station in 1930, and*** **b)** ***Antenna system at the beam radio station, Bridgwater in 1926***

Sir Basil Blackett, Chairman of the newly organized Imperial Communications Company, and other important people. Describing the demonstration, Sir Robert wrote:

'We were witnessing the successful demonstration of transmitting speech over a distance of more than 3 000 miles on the same wavelength simultaneously with two wireless telegraph messages. While we were using the desk telephone in the office of the station, the tape was running off written telegraphed messages in the operating room at the rate of hundreds of words a minute. These were being relayed to London without interruption. The invention is a unique combination of efficiency and economy. The system may be incorporated in all 'Beam' stations on the Imperial Chain, avoiding the necessity for new stations for telephonic communication.'

'The advantages of the Marconi Multiplex System, as it is called, are many. It is more efficient and incomparably cheaper. It does not involve the reconstruction of stations. It enables a short wave to be used. There is great economy in power; and there is almost complete secrecy. No one could have listened to our conversation except through a similar installation. What is being accomplished on the Canadian circuit can be carried out between other parts of the Empire. Already an apparatus is being made for the South African Beam station. The universal adoption of the system would enormously cheapen telephonic communication throughout the Empire.'

This opinion of the Multiplex System from an independent observer such as Sir Robert Donald, whose experience as Chairman of the Imperial Wireless Telegraphy Committee makes his views of unusual weight, should have been of the greatest value to all who are interested in the establishment of wireless telephone services over long distances. It was not to be though. The system seemed to be incompatible with the interests of the new merger of Cables and Wireless in 1929. A modern HF sound broadcast transmitter, made by GEC-Marconi Communications Ltd. for the BBC, is shown in fig. 8.

8 *One of two 500kW HF sound broadcast transmitters installed at Rampisham, Dorset, for the BBC by GEC-Marconi Communications Ltd.*

Blind Navigation by Microwaves

In 1928 the Italian Government, at last recognizing that Marconi's reputation and influence would be a most valuable political asset at that time, set about creating a situation in which permanent residence in Italy would be an attractive proposition to him.

So it happened that Marconi was given the responsibility of founding the Italian Research Council and became its first President. In 1929 the hereditary title of Marchese was conferred upon him by the King of Italy, and in 1930 he was nominated President of the Italian Royal Academy.

It is not difficult to understand that Marconi was in a unique position. It was, perhaps, an understatement when he said about his personal circumstances: 'I enjoyed special facilities and was afforded every possible assistance and encouragement by the Italian Government'. The Italian Government was therefore most enthusiastic when Marconi expressed the wish to continue his wireless experiments in Italy.

Over the years Marconi had been obsessed with the fear that, having commenced his experiments with wireless on a wavelength of 30 centimetres in 1894–6, he had perhaps missed something important by allowing himself to be deflected from fully exploiting them by taking the slippery slope to longer and longer wavelengths in order to achieve greater and greater distances of practical communication. As an example, in the paper he read before a radio audience in New York in 1922[3], he said:

'The progress made with the long waves was so rapid, so comparatively easy and so spectacular, that it distracted practically all attention and research from the short-waves and this, I think, was regrettable, for there are very many problems that can be solved and numerous most useful results to be obtained by – and only by – the use of the short-wave system'.

Marconi, probably remembering that he had consigned to the scrap-heap his parabolic reflectors for use with the 30 centimetre wavelength decided to re-open those early experiments where the use of that kind of reflector would again be necessary.

In 1932, after two years of experimentation, he gave an account of his work in a paper he read to

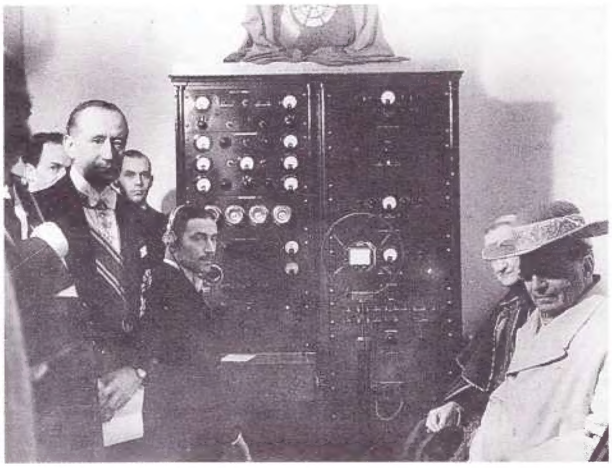
the Royal Institution in London[4], where he described the work he had recommenced on wavelengths of the order of 50 centimetres. He first of all described the difficulties under which his new experiments were carried out because of the absence of those facilities, or 'tools of the trade', that are now available to the modern experimenter. There were no radio devices for the measurement of power, signal intensity or indeed wavelength itself. This fact explains the absence of the precise measurements to which we have become accustomed in recent years – it may serve also to enhance his technical achievements.

It was with crude and simple apparatus, which he had designed, that Marconi set out supremely confident that he would, yet again, confound the false prophets of the day who were of the opinion that transmission of his microwaves beyond the horizon was impossible. In the Royal Institution paper he said:

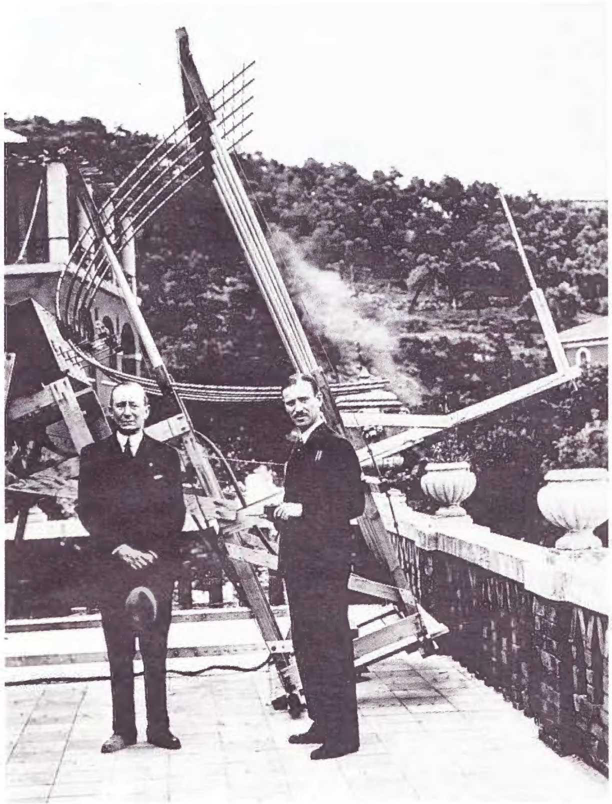
'Long experience has, however, taught me not always to believe in the limitations indicated by purely theoretical considerations or even by calculations, for these – as we well know – are often based on insufficient knowledge of all the relevant factors, but, in spite of adverse forecasts, to try out new lines of research, however unpromising they may seem at first sight.'

By 1932, Marconi was able to demonstrate a microwave two-way telephone system across the Ligurian Bay in the Mediterranean. The two terminals were situated one at Santa Margherita the other at Sestri Levante, a distance of 12 miles. The demonstration so impressed the Vatican Authorities that Marconi was requested to install a similar system between the Vatican City and the summer residence of His Holiness the Pope at Castel Gandolfo. The Vatican installation was inaugurated by His Holiness in February 1933 and is recognized as the first microwave telephone subscriber link in the world (figs. 9a and 9b).

Marconi was satisfied that he had sufficiently demonstrated the usefulness of microwaves for relatively short communication links, and he was content to leave it to his commercial organization to develop the idea. His ambition was clearly to break down the barriers which appeared to him to be imposing an unreasonable limitation upon the transmission of microwaves over substantial distances. With this in mind, and disregarding the opinion of the wise men who 'knew' that microwaves could not be transmitted beyond the horizon, he set about studying in more detail the laws governing their transmission characteristics over greater and greater distances. In this extended work the use of Marconi's yacht, the S.Y. 'Elettra',



a)



b)

9 a) ***Inauguration of the first microwave telephone service between the Vatican and Castel Gandolfo, the Pope's summer residence. On the right is His Holiness the Pope, Pius XI, with Cardinal Pacelli (who became Pope Pius XII) by his side. On the left stands Guglielmo Marconi, G. A. Mathieu (wearing headphones), and Gerald Isted in the background – both assistants of Marconi, and at the extreme left in the background is Padre Gianfranceschi, Director of the station.*** b) ***Part of the microwave radio link, with Marconi on the left and Mathieu***

was invaluable and, with it, signals were received over routes that were several times the distance of the horizon. On one such test, a distance of nine times the optical range was easily achieved.

It was typical of Marconi that he should follow an Easter-time custom in Italy to invite the church dignitaries to attend the yacht 'Elettra' to bless his family, his yacht, and the experimental work he was doing. The local Cardinal came with his attendants, starting at one end of the yacht sprinkling holy water on this and that, with an olive branch. He finally ended up at the wireless cabin where Landini, a wireless operator, and the writer were waiting. Landini fell to his knees to kiss the ring on the Cardinal's finger and the same was offered to the writer who, not going on his knees to any man, just shook his hand. The Cardinal continued sprinkling with his olive branch until they were due to leave the cabin, but not before giving the writer a very adequate dose of water as he left the cabin. Marconi came to the rescue and explained that the writer was an 'ingegnere Inglesi' !

Marconi made no secret of the fact that he hoped one day, with improved equipment, to find evidence of an elevated layer which would reflect microwaves in a similar fashion to the reflection of longer wavelengths by the ionosphere. Accordingly, it was routine procedure to determine the best vertical angle of transmission by tilting the parabolic aerials upwards in prescribed stages. His most ambitious tests in this respect were carried out between an extinct volcano, Rocca di Papa, near Rome, and the 'Elettra' anchored in the harbour at Venice – a distance of 300 miles. The experiment failed, then, partly because of insensitive apparatus. It is interesting to note, though, that Marconi's intuition was uncannily correct, for, thirty years or so later, communication links operating on slightly shorter wavelengths were installed between the North Sea oil rigs and the mainland, at distances approaching 200 miles, utilizing the so-called tropospheric scatter as the medium.

Throughout his career Marconi was always seeking ways and means of ensuring the safety of ships at sea. This urge was particularly keen while he was investigating the possibilities of utilizing microwaves, and it was in the field of marine navigation by microwaves that he gave a most spectacular demonstration which, sadly, was also to be his last.

In 1934, Marconi conceived of the idea of guiding a ship through a narrow entrance to a harbour in conditions of zero visibility. To demonstrate this he arranged to have mounted, at right-angles to one another, two broad-beam parabolic reflectors with their respective horizontal aerials energized in opposition from a common transmitter. In this way a very sharp zone of minimum signal was created in the centre of an otherwise broad region of high signal level. The whole aerial head was then made to oscillate to and fro by about plus and minus fifteen degrees so that the sharp minimum scanned a sector of thirty degrees.

In addition, the transmitter emitted two tones alternately, the change over from one tone to the other taking place when the aerial minimum was directed exactly along the desired navigation course.

On board the 'Elettra' a four-valve receiver, which had been used so successfully in all previous experiments, was modified by incorporating two tone separators corresponding to the two modulation tones applied to the transmitter. The outputs from their respective detectors were then applied to a centre-zero-indicating instrument. By this arrangement, the pointer of the indicator was deflected left and right (port and starboard) according to the tone being received at that moment.

When the 'beacon' head was scanning correctly left and right about the desired approach course, the indicating instrument would be deflected equally, also left and right, provided that the ship was correctly positioned on the approach course. Should the ship deviate from the predetermined course, an unequal deflection to left or right would be noted on the indicator. All that was necessary to keep the ship on the desired approach course was to ensure, by altering course if necessary, that equi-deflection was maintained on the indicator.

The early tests proved to be so successful that Marconi, in a very confident mood, planned a very elaborate demonstration, and invited on board the 'Elettra' representatives from all the big British shipping lines and from Trinity House.

For the demonstration, the navigation beacon was installed on the promontory at Sestri Levante at a height of 90 m above sea level. Two buoys were then anchored 90 m apart at a distance of 800 m from the shore to simulate a harbour entrance.

On July 30th the 'Elettra' steamed out to sea from her anchorage at Santa Margherita with Marconi's guests on board. With all the blinds of the wheel-house drawn so that it was impossible for the navigator to see, the yacht was successfully steered between the two buoys solely by means of the indication given by the beacon. The manœuvre required little skill and many of the guests took turns to do it themselves (fig. 10).

10 ***Artist's impression of the 'Elettra' during blind navigation trials – wheel-house blinds shown un-drawn (Painting by Chris French)***

The success of the demonstration caused great excitement amongst the guests – but more was yet to follow. Marconi had also arranged for two similar buoys to be anchored at the entrance to the harbour at Santa Margherita. By turning the receiver to face astern, and by reversing the connections to the indicator, Marconi then proceeded to carry out the same manœuvre, again most successfully, but this time at a distance of 16 km from the beacon! This, one must remember, happened over forty years ago! One is tempted to ask, with the sophisticated apparatus now available, could we do much better today?

Fig. 11 shows the next generation of satellite navigationequipment being jointly designed and built by Matra Marconi Space (UK) and GE Astro-Space (USA).

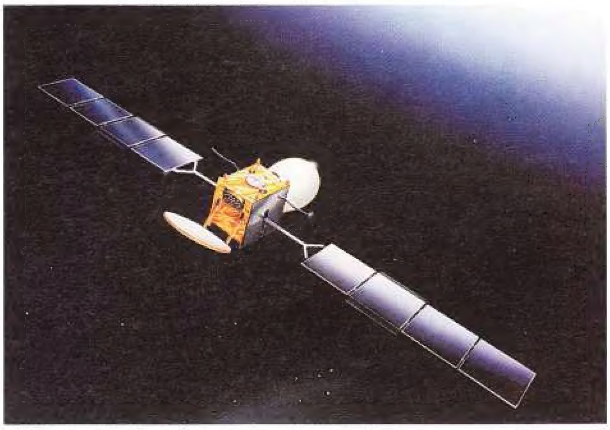
Postscript

Looking back over the years one is left with the thought, notwithstanding the painstaking experimental work that Marconi performed in the closing years of his life, his findings in the period 1932 until his death in 1937, for the greater part, fell on deaf ears. The world at large was not ready to follow his lead. It was to be two decades, in some instances, before physicists and communication engineers continued from where Marconi left off!

Acknowledgements

I gratefully acknowledge the facilities afforded to me by the Marconi Companies. In particular I thank the late Mrs. Betty Hance, the former Marconi Historian, for her help and encouragement without which this history would never have been written. I thank the former Marconi Research Librarian, Mr. Ted Easteal for being ever ready to provide me with technical publications. I also gratefully acknowledge the information I have freely taken from the publications listed in the bibliography. Last, but by no means least, to Miss Honor Harris, my secretary before I retired, I shall be eternally grateful for undertaking the necessary typing. Only she could possibly have read my writing.

Reference (4) is included by courtesy of The Royal Institution.



a)

b)

11 a) *Artist's impression of Inmarsat-3. This series of satellites is being designed and built by GE Astro-Space of the United States and Matra Marconi Space (UK). The first satellite is scheduled for delivery in 1994.* b) *The Inmarsat-3 navigation antenna under test on the antenna test range at Matra Marconi Space (UK), Portsmouth. (courtesy Matra Marconi Space)*

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